A Novel Python Tool for Analyzing Geant4 Simulations: Enhancing Understanding of Channeling in Crystals

Channeling 24

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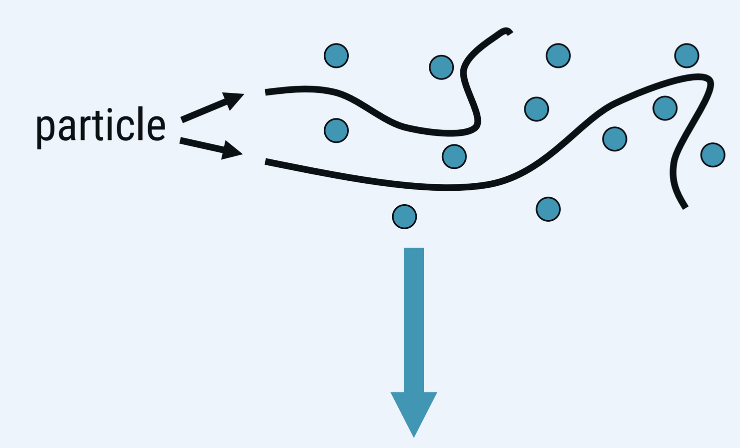
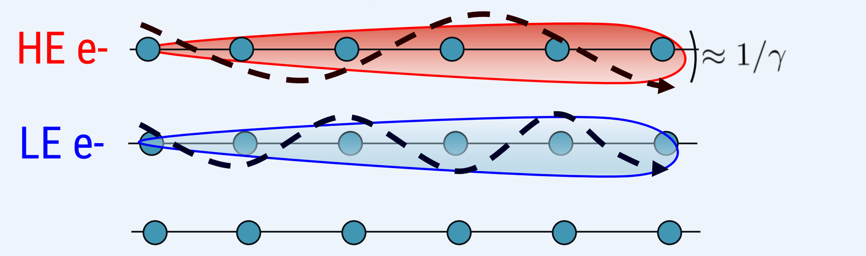
Motivations

A novel Python tool for the analysis of Geant4 simulations that enhances our understanding of coherent phenomena occurring during the interaction of charged particles with crystal planes. This tool compares the total energy of particles with the potential energy inside crystal channels, enabling a complete examination of coherent effects. By tracking and tagging the dynamics of each simulation step, it provides deeper insights into how different phenomena contribute to both radiation and particle deflection. This tool can play a key role in improving crystal-based extraction methods and the development of gamma-ray sources using crystals.

Coherent effects





$$\theta_c = \sqrt{\frac{2U_0}{pv}}$$ Channeling Radiation [1,2]

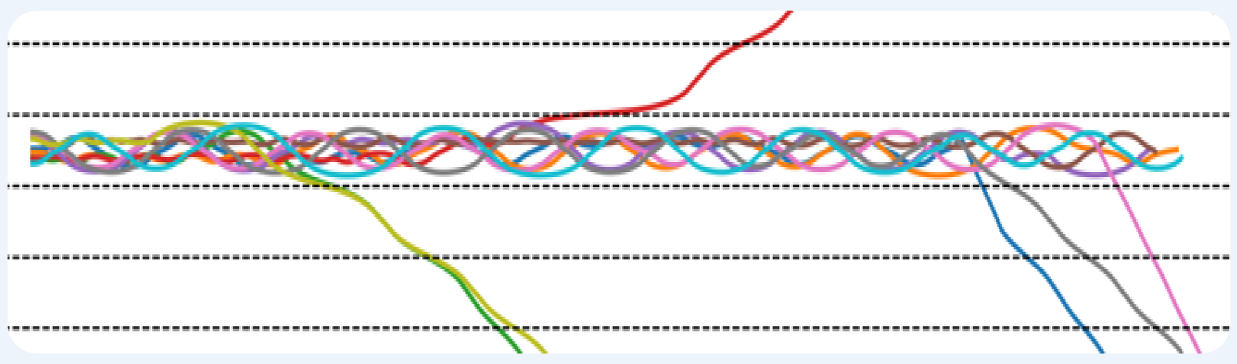
Low Energy (<GeV) → **dipole radiation** (undulator)

High Energy (>>GeV) → **synchrotron radiation** (wiggler)

Classification Procedure

Extract the information from the crystal Geant4 model for each event ID:

- Trajectory
- θ_x for each step [3,4]
- Final out angle
- Emitted photons



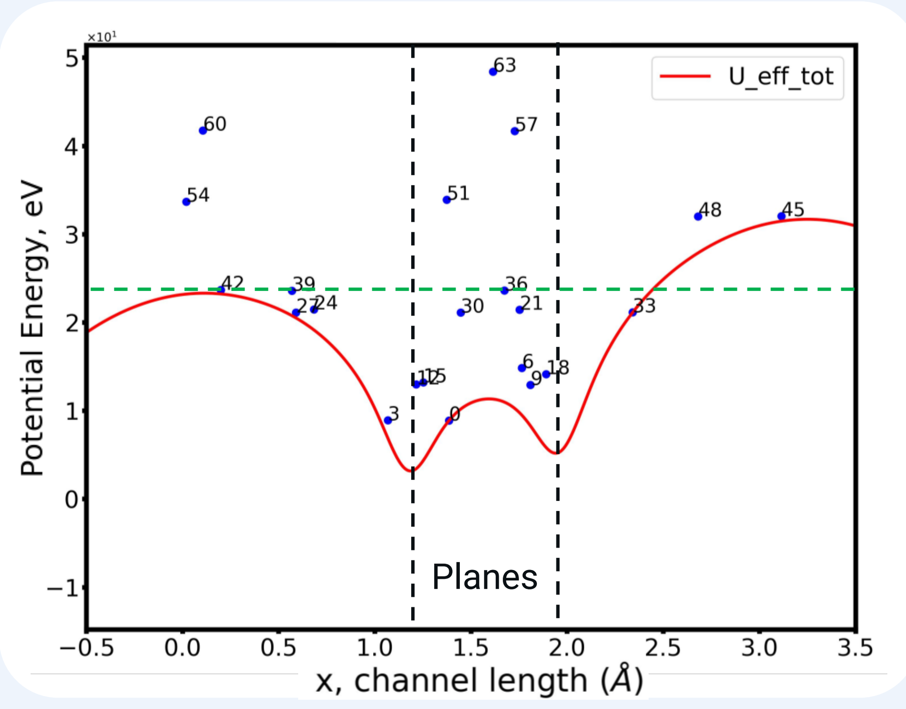
For straigth and bent crystals → more interesting case

$$E_T = \frac{pv}{2}\theta^2 + U_{eff} \qquad U_{eff} = U(x) + \frac{pv}{R}x$$

For each step in the trajectory the value of the **Transverse Energy (E_T)** and the corresponding value of the **Effective Potential (U_{eff})** is compared to determine a «state»:

$$E_T < U_{eff}(x=0) \rightarrow CHANNELING$$

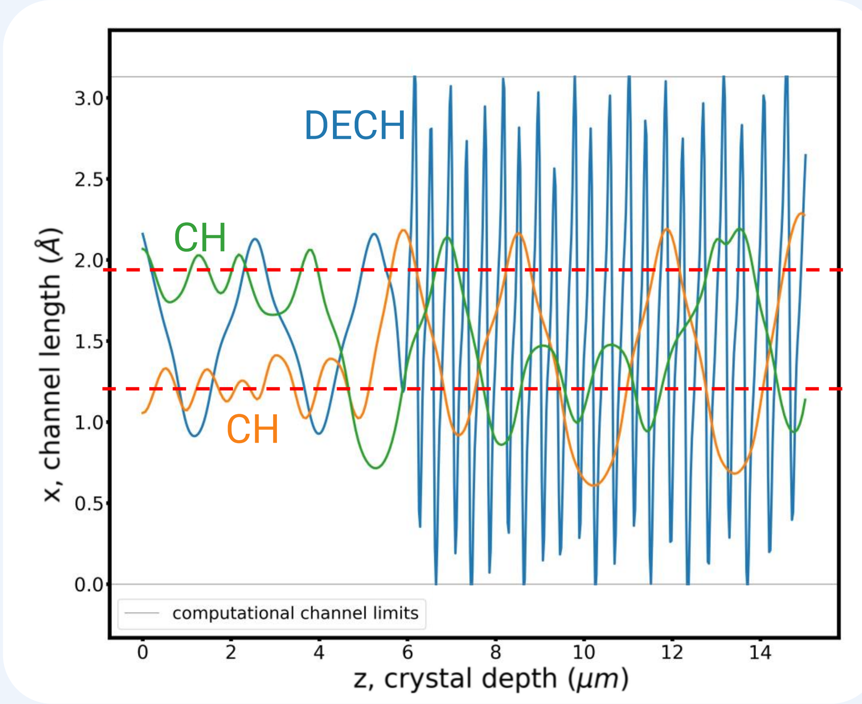
$$E_T > U_{eff}(x=0) \rightarrow OVERBARRIER$$



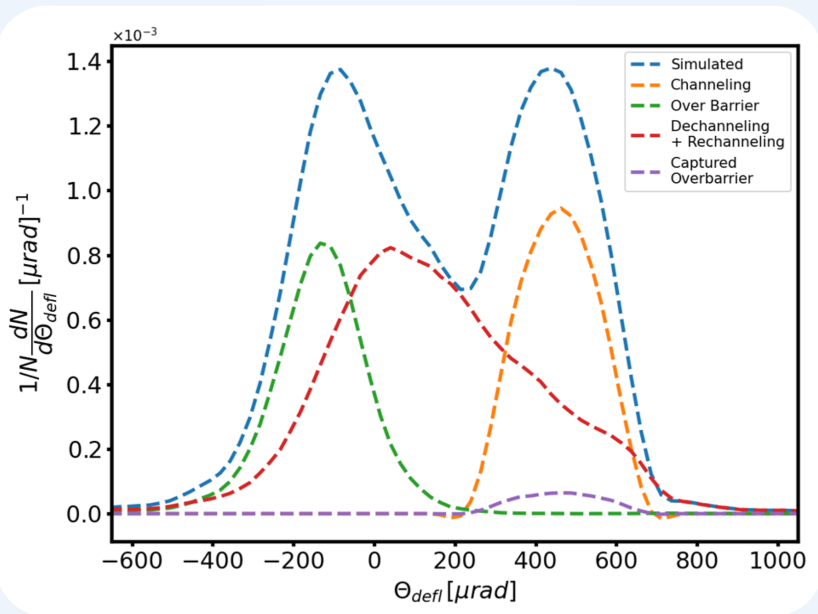
We obtain the list of states for the whole trajectory that then can be classified to:

- **Channeling**
- **Overbarrier**
- **Dechanneled**
- **Captured Overbarrier**
- **Rechanneled** (of different orders)

Based on specific conditions (the core of the classification)



Dynamics Classification



The output of the classification can be used to study how the different phenomena can influence the dynamics of the particles inside the crystal.

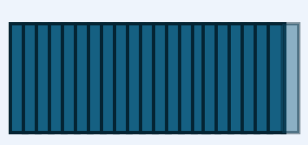
[5,6]

For example in the **deflection profile.**

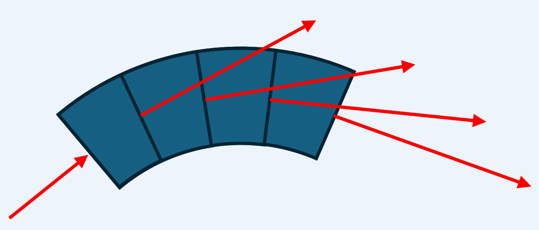
By simulating crystals of different dimensions and extract the number of channeled particles at the exit we can obtain a set of points that can be fitted using a negative exponential function to obtain the **dechanneling length**.

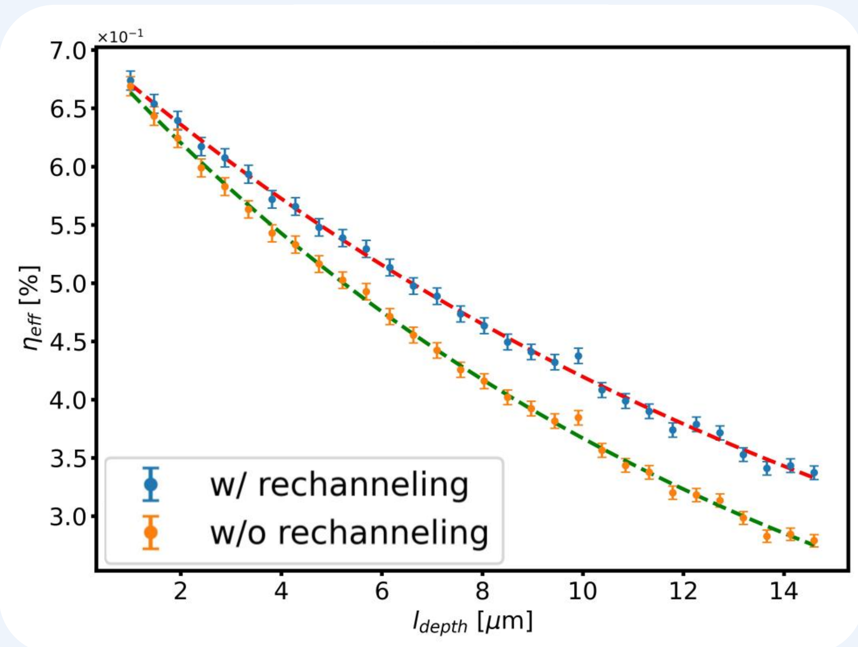
$$N_{channeled}(z) = N_{channeled}(z=0)e^{-z/L_d}$$

Straight crystal



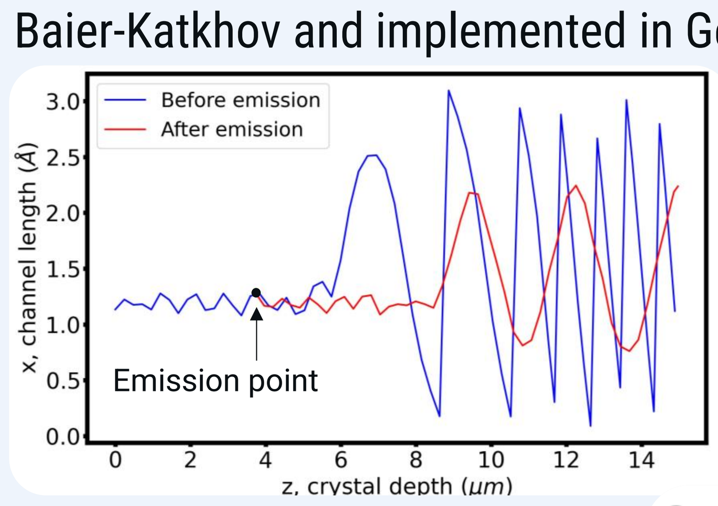
Bent crystal





Radiation Classification

The radiation calculations are based on the semiclassical approach developed by Baier-Katkhov and implemented in Geant4 **[3,4]**.

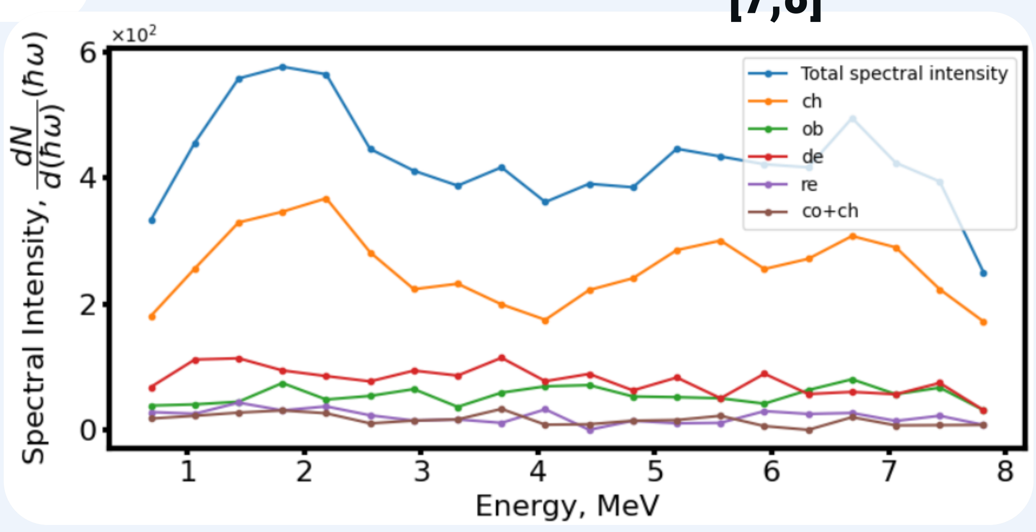


In this case the trajectory used to classify the particle is the segment until the point of emission, that is the one that influenced the photon production. Multiple photon emissions are included.

[7,8]

The result can be used to study how the different phenomena can influence the radiation emitted by particles inside the crystal.

For example: **Spectral Intensity.**



Future developments:

- Convert to C++ and add it directly in the Geant4 crystal model
- Possibility to set specific materials through .cif files
- Train a Neural Network to do the classification of the trajectories
- Implement the Periodic bending case (undulator)

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